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# HEAT TRANSFER TO A GAS CONTAINING A CLOUD OF PARTICLES

by

J. Andrew McAlister, Edward Y. H. Keng, and Clyde Orr, Jr.

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

29598

The basic radiation equations were solved to describe the radiant heat transfer from a black, cylindrical enclosure uniformly radiating to a black, evenly dispersed particle cloud contained within. Back thermal radiation and radiation scattering were considered negligible. The solution was presented graphically in generalized form with all variables being dimensionless quantities, and comparisons with experimental data were shown. Equations were also presented for calculating the radiation absorbed by a particle cloud within unheated segments of the enclosure adjacent to the radiating element. A brief description of particle deagglomeration and cloud transmissivity studies was included.

*Author*

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## I. SUMMARY

The purpose of this study is to provide basic information about the absorption of radiant energy by particle clouds. To date, theoretical and experimental studies of the radiant heat transfer in cylindrical enclosures have been made. Other investigations concerning particle cloud generation, radiation transmissivities, and heat transfer to particle clouds composed of submicron carbon particles are in progress.

A theoretical formulation, describing the radiant heat transfer from a cylindrical radiating wall to particles suspended within it, has been derived by the integration of basic radiation equations. The result was generalized and presented in graphical form so that radiant heat transfer calculations may be made for systems having practically any length-to-radius ratio and having absorption characteristics ranging from nearly transparent to almost totally absorbing. The particle surfaces must be black for the result to be exact. Some adjustments can be made for imperfect absorption, however. Experimental data, previously collected in this study, were compared with the theoretical predictions and good agreement was found. A method for calculating the radiant heat transfer to particles in unheated extensions from an enclosure was also derived.

Recent experimental work has been concentrated on the achievement of more effective particle dispersion and the determination of the radiation transmissivities of particle clouds. Primary efforts, however, are on the designing of a particle cloud generator which will give the best particle dispersion now possible. This problem takes precedence over other heat transfer and radiation transmissivity studies since the results in the latter cases depend to a very high degree on the extent of particle agglomeration.

A device has been constructed in which a gas-particle mixture is caused to expand continuously through a small sharp-edged orifice. The rapid expansion at the orifice creates an intense shearing action which is capable of acting across very small agglomerates and breaking them apart. Pressures up to 1500 psig are being employed. Particle clouds of carbon black have been prepared in which more than one-half of the agglomerates were less than 0.2 micron in diameter.

A system for measuring particle cloud transmissivities has also been constructed. A Beckman Model B spectrophotometer (Beckman Instruments, Inc., South Pasadena, California) is serving as the transmissivity measuring device. Gas-solids suspensions are passed through a rectangular conduit and by means of air-cleaned windows a fixed distance apart are exposed to monochromatic radiant beams generated by the spectrophotometer. The decrease in intensity caused by the particles is indicated on the photometer. An entrance surge-chamber smooths variations in particle cloud concentrations. The unit is in operation, but sufficient quantitative data have not yet been accumulated to give meaningful results. Before these measurements can be fully analyzed a method for determining the particle concentration must be developed.

It is anticipated that work in the near future will be primarily experimental with each area of interest -- heat transfer, particle cloud generation, and radiation transmissivity -- being pursued.

## II. INTRODUCTION

The purpose of this study is to provide basic information about the absorption of radiant energy by particle clouds. In particular, cloud geometries are of interest which are cylindrical in shape and which may be of use in the evaluation of proposed nuclear rocket designs. Recent efforts have been to analyze the radiant heat transfer process for a uniformly radiating cylinder wall to an evenly dispersed particle cloud within it. These results are summarized here, but a comprehensive treatment of them is available in a special report released in June, 1965. Current studies are concerned with methods of particle cloud generation and transmissivity measurements on these clouds. A revised experimental approach is also being planned to study the radiant absorption characteristics of clouds composed of submicron particles.

### III. RECENT THEORETICAL HEAT TRANSFER STUDIES

During the past year and particularly in the last reporting period, extensive efforts were devoted to the calculation of the direct radiant heat transfer from a uniformly radiating cylinder wall to an evenly dispersed particle cloud within the enclosure. Calculations were also developed for the direct radiant heat transfer to particles contained in adjacent, unheated, extensions of the enclosure. While a comprehensive treatment is given in a recent Special Report, a brief summary is presented here.

#### A. Development of Equations and Calculated Results

If the basic relationships for black body radiation are considered, the net radiant interchange between two black surfaces may be described by

$$Q_b' = \int_{A_2} \int_{A_1} (i_{bn2} - i_{bn1}) \left( \frac{\cos \beta_1 \cos \beta_2}{S^2} \right) dA_1 dA_2 \quad (1)$$

where  $i_{bn1}$  and  $i_{bn2}$  are the black body radiation intensities normal to the differential area  $dA_1$  and  $dA_2$ ,  $\beta_1$  and  $\beta_2$  are the angles between the normal direction to the surfaces and the line segment  $S$  connecting them. For the particular problem investigated here the geometric variables are shown in Figure 1, this expression becomes

$$Q_b = \int_0^{2\pi} \int_0^{2\pi} \int_0^R \int_0^L \int_{-z}^{L-z} (i_{bnw}) \left( \frac{e^{-kS}}{S^2} \right) \left( \frac{S^2 + R^2 - r^2 - y^2}{2RS} \right) r dy dz dr d\psi d\theta \quad (2)$$

where the radiation intensity is attenuated exponentially with distance ( $e^{-kS}$ ) and the particles were sufficiently low in temperature not to back radiate significantly to the wall, i.e.,  $i_{bnp} = 0$ . The other terms are:  $i_{bnw}$ , the normal wall intensity;  $L$ , the cylinder length;  $R$ , its

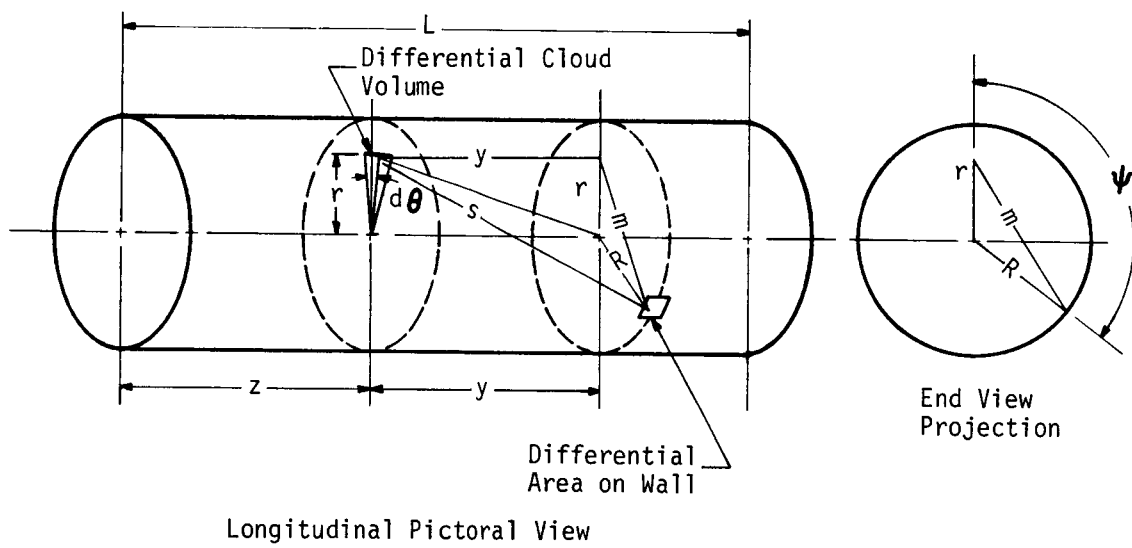


Figure 1. Definition of Geometric Variables for Tube Radiating to Enclosed Particle Cloud.

radius;  $y$  and  $z$  (distance); and  $\psi$  and  $\theta$  (angles) describing the geometric location of a differential wall element  $dA_w$  that radiates to a differential amount of aerosol surface  $dA_p$ . The integral heat transfer equation was re-written as

$$Q_b = (2\pi R)(i_{bnw})(k) \int_0^R \int_0^{2\pi} I r d\psi dr \quad (3a)$$

where

$$I = \int_0^L \int_{-z}^{L-z} \left( \frac{e^{-kS}}{S^2} \right) \left( \frac{S^2 + R^2 - r^2 - y^2}{2RS} \right) dy dz \quad (3b)$$

and the  $\theta$  integration was performed to give the coefficient  $2\pi$ . The integral  $I$  was evaluated analytically by means of a series expansion of  $e^{-kS}$ . The subsequent integrations for  $\psi$  and  $r$  were performed numerically by use of closed form Newton-Cotes quadrature formulae. The integral equation was solved first for a particular set of conditions applying to a concurrent experimental investigation; calculations were made later to apply to other systems.

A generalized correlation was produced for radiation systems of specific interest to this investigation that related the rate of heat absorption, radiation intensity, cylinder length and radius, and particle cloud attenuation constants. The results are given in Figure 2 where  $Q_b/(i_{bnw})(\pi R^2)$  or  $E_b$  is plotted versus  $L/R$  with  $kR$  as a parameter.

The ordinate represents the rate of heat absorbed per unit radiation intensity per unit cross sectional area and is solely determined by the geometrical term  $L/R$  and the absorption parameter  $kR$ . For a constant  $L/R$ , the absorption ordinate increases with the absolute value of  $kR$  and finally when  $kR$  is infinite the absorption is a maximum given by the uppermost line. This

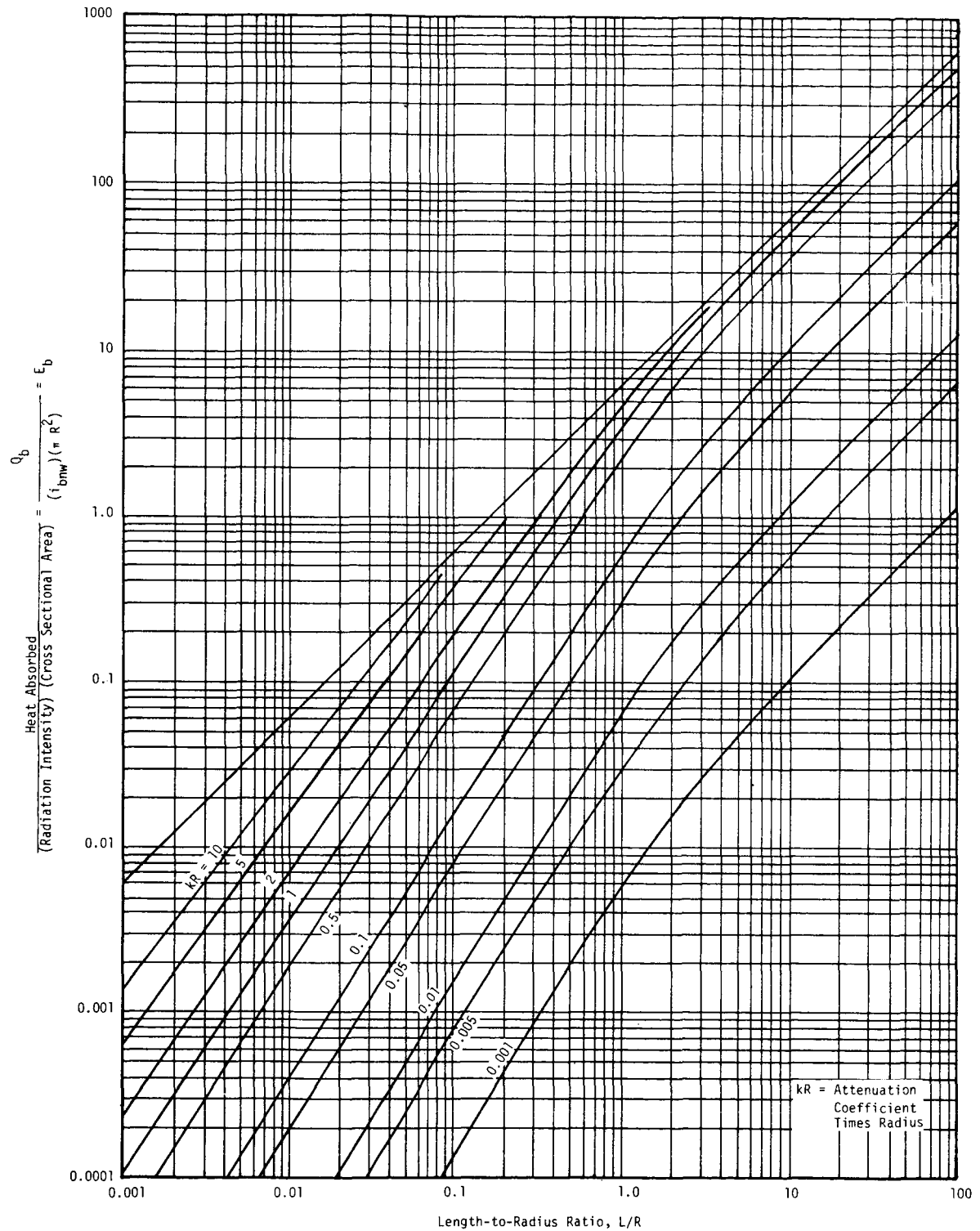


Figure 2. Generalized Correlation for the Absorption of Radiant Energy by an Evenly Dispersed Particle Cloud within a Uniformly Radiating Cylindrical Enclosure.

limiting curve represents the total emissive power of the system enclosure, and the equation for it is

$$\frac{Q_{\text{emit}}}{(i_{\text{bnw}})(\pi R^2)} = \frac{(\pi)(i_{\text{bnw}})(2\pi RL)}{(i_{\text{bnw}})(\pi R^2)} = 2\pi\left(\frac{L}{R}\right) \quad (4)$$

Because the total emitted energy is represented, the plot has the desirable feature that the absorption efficiency is immediately available by inspection; it is only necessary to divide the ordinate for a given system by the total emission represented by the uppermost curve. The efficiency, then is

$$\gamma = \frac{\frac{Q_b}{(i_{\text{bnw}})(\pi R^2)}}{\frac{Q_{\text{emit}}}{(i_{\text{bnw}})(\pi R^2)}} = \frac{Q_b}{Q_{\text{emit}}} \quad (5)$$

Each parametric curve has three distinct regions classifiable by the  $L/R$  ratio. For very small or very large values of the abscissa, each curve is very nearly a straight line. Between these regions each curve has a variable slope such that the functions are smoothly continuous between the two characteristically linear regions. The linear extensions of the curves make them suitable for indefinite extrapolation.

#### B. Construction of Additional Parametric Curves

While the generalized graph gives accurately the effect of the geometric variables, the particle cloud absorption properties were limited to selected parametric curves for  $kR$ , and interpolation between them is uncertain. The data, however, may be replotted to yield results for any value of  $kR$ , if  $L/R$

is made the parameter. The graph, for the most part, is very nearly linear, except near total absorption, and results for a particular  $kR$  can be read very accurately. If only one system is being studied, the plot is made for the required  $L/R$ . If, however, a completely new parametric curve is needed the process is repeated for several  $L/R$  values and as many points as desired can be plotted on the generalized graph, and the new curve constructed. Five charts of this nature are given in Figures 3 through 7 for several widely spaced  $L/R$  values. The construction of additional curves by this method is very accurate and results from the procedure were checked with the computer and almost exact agreement was found. For points near total absorption, however, calculated data were not obtained because of arithmetic or exponential overflows in the computer operations, unsuitable accuracy in partial results, and unsatisfactory convergence. Extrapolation of these data to  $kR$  values larger than those given may be attempted but the results will be outside the range of computations.

#### C. Use of the Generalized Chart

The generalized graph was developed specifically for the evaluation of the absorption of radiant energy by clouds of uniformly dispersed black particles while within a black, uniformly radiating cylinder. The result for a particular problem is obtained by forming the length-to-radius ratio and the absorption parameter,  $kR$ ; determining the corresponding ordinate for these values; and multiplying this number by the radiation intensity and the cross sectional area of the enclosure. The result is the heat absorbed by direct emission from the radiating wall; the value divided by the total emission from the enclosure gives the particle cloud absorption efficiency. This is the primary use of the generalized graph.

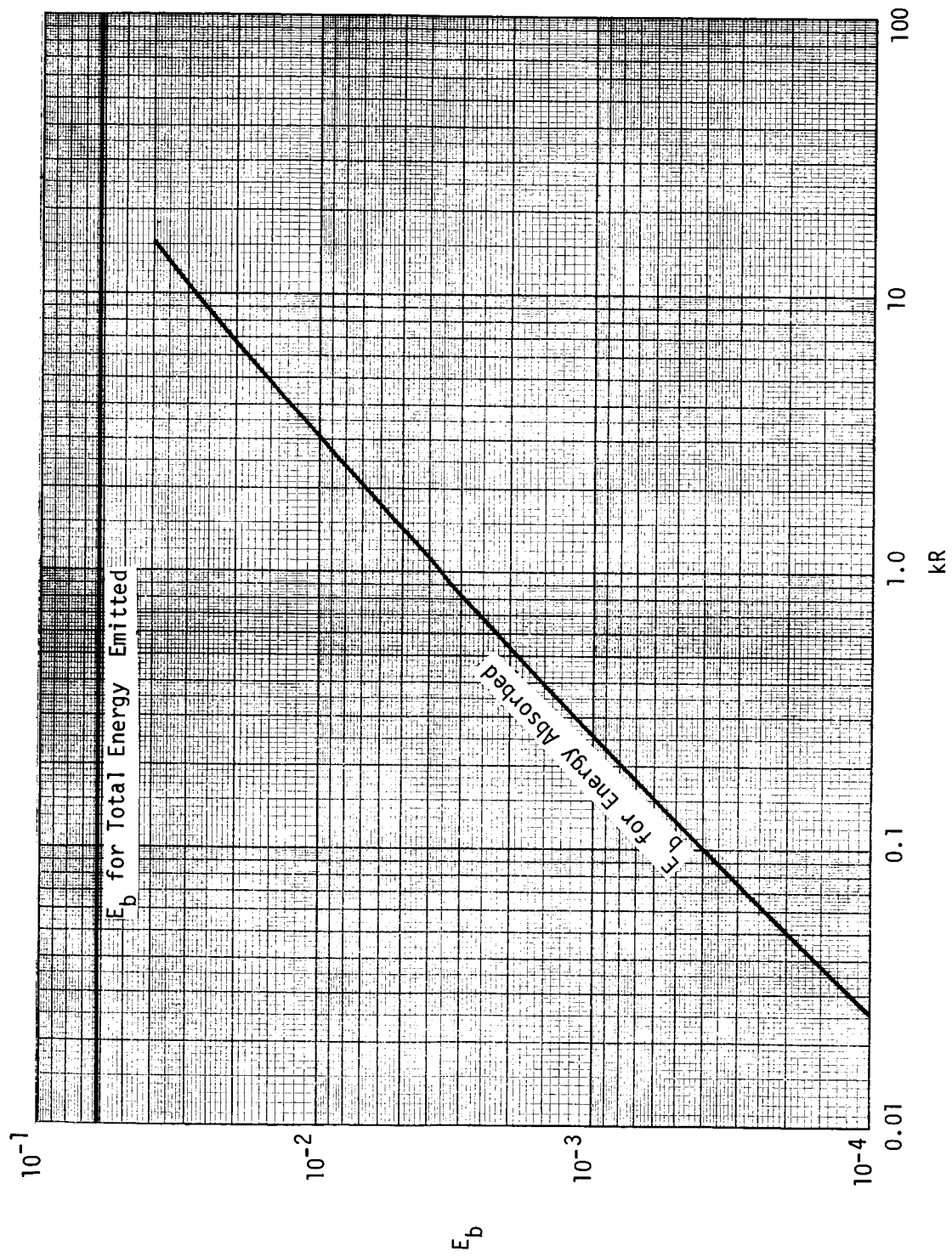


Figure 3. Generalized Results for a Length-to-Radius Ratio of 0.01.

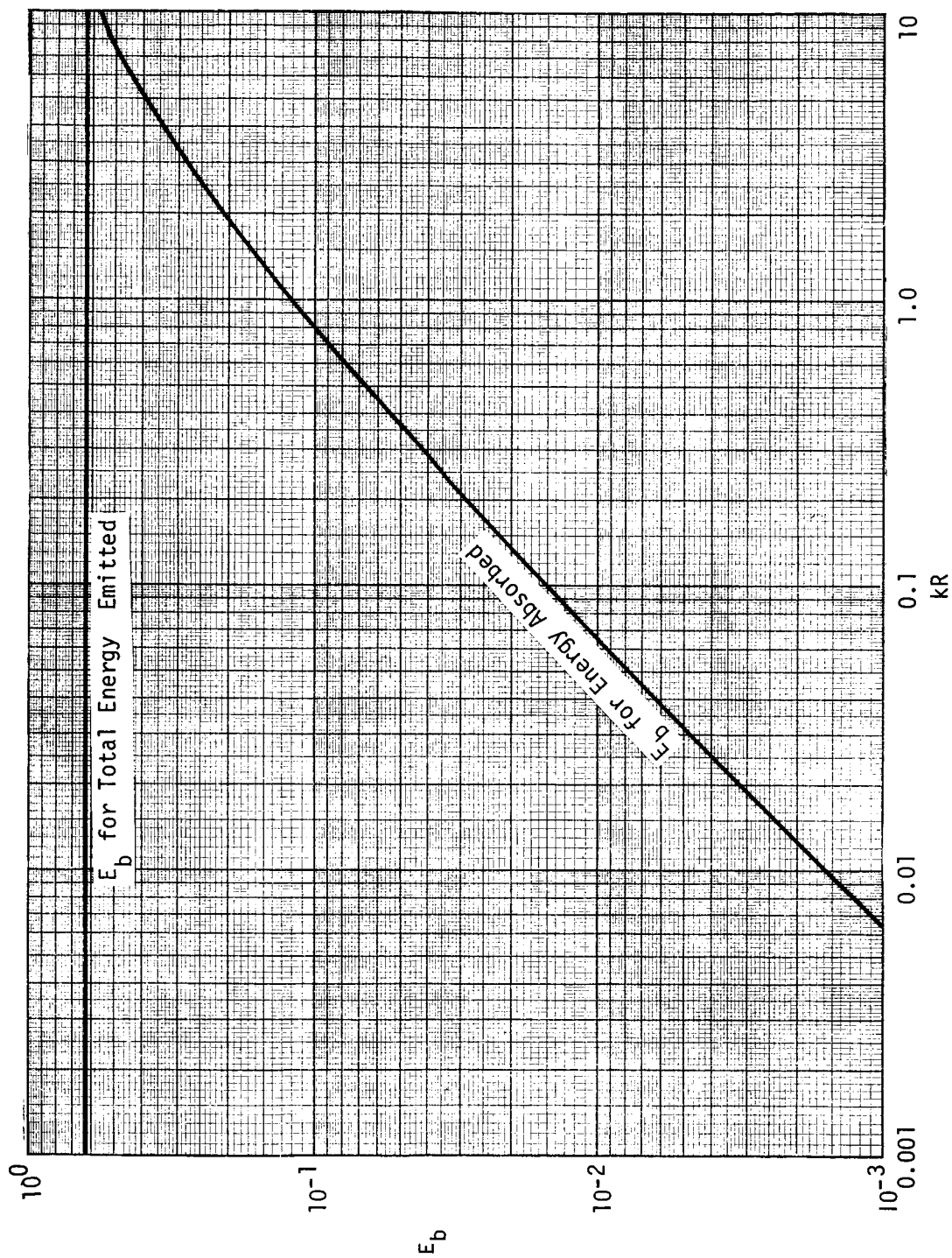


Figure 4. Generalized Results for a Length-to-Radius Ratio of 0.1.

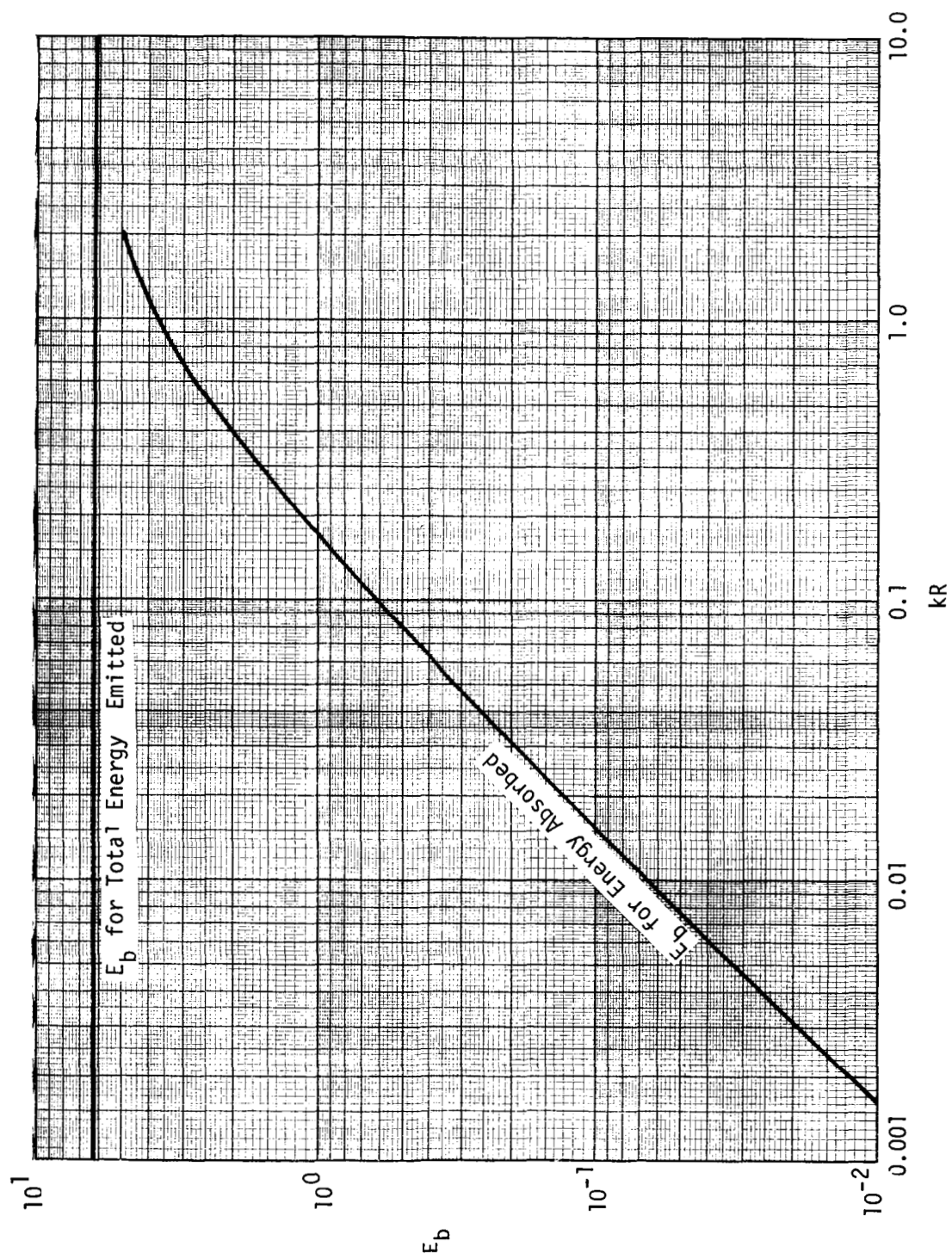


Figure 5. Generalized Results for a Length-to-Radius Ratio of 1.0.

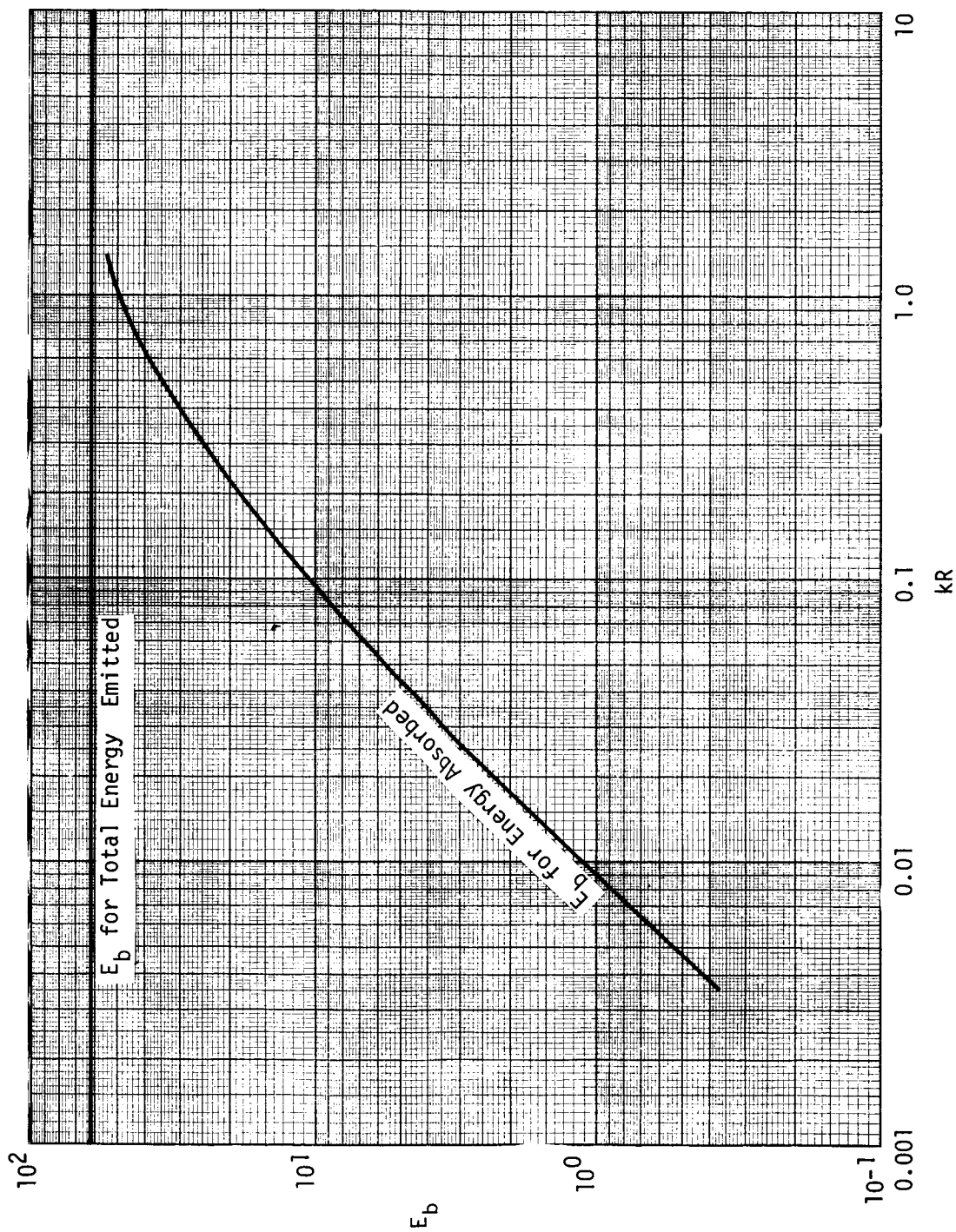


Figure 6. Generalized Results for a Length-to-Radius Ratio of 10.0.

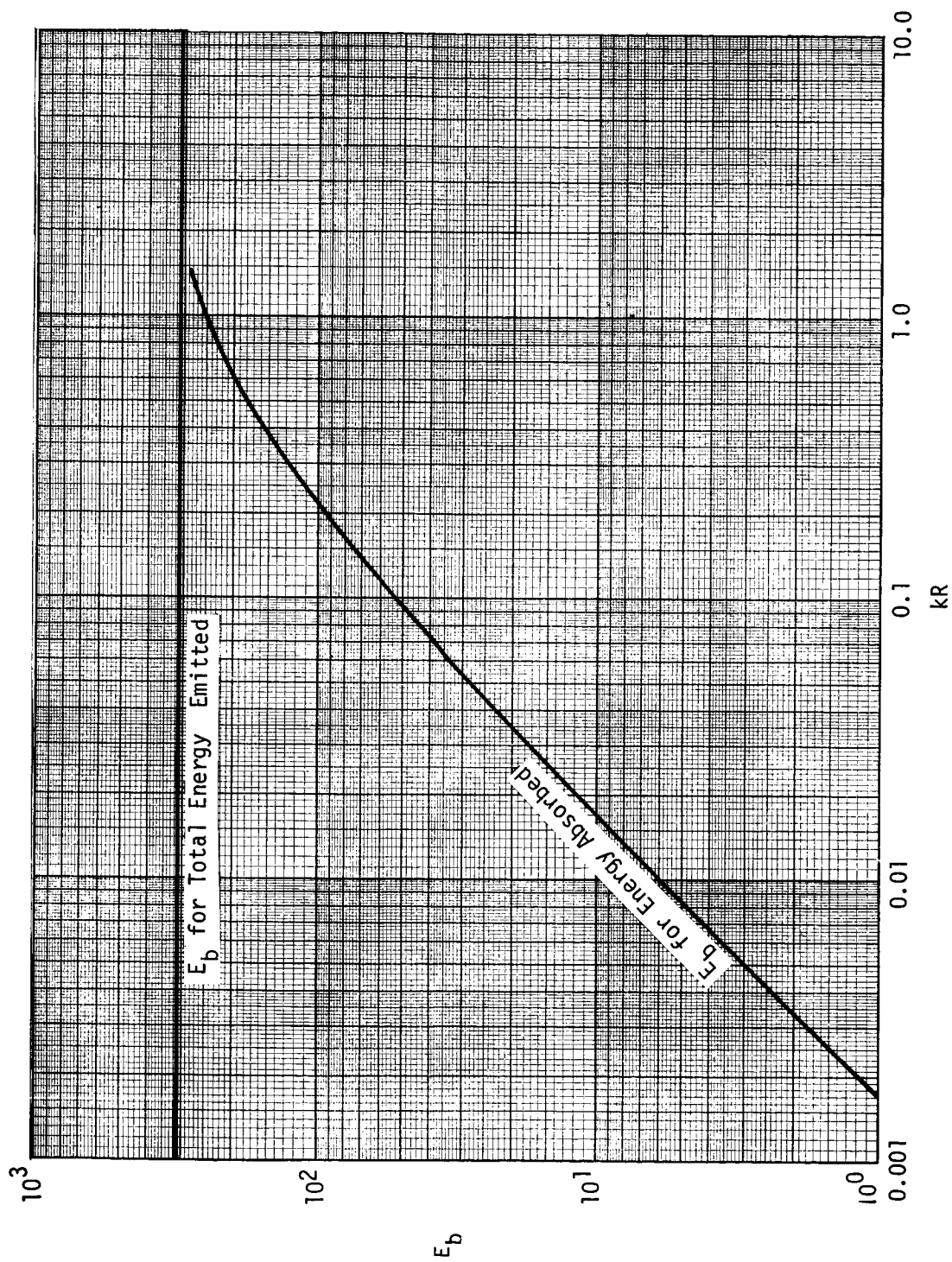


Figure 7. Generalized Results for a Length-to-Radius Ratio of 48.906.

If the total length of an enclosure is not heated and unheated sections extend beyond the heated region, there is additional absorption of radiation by particles entrained in the unheated extensions.

The relationship

$$\Delta E_x^{nx} = \frac{E_{(n+1)x} - E_{nx} - E_x}{2} \quad (6)$$

gives the absorption by the particle cloud while it is in an unheated extension having a length-to-radius ratio  $x$  that is adjacent to a heated portion of enclosure having a length-to-radius ratio of  $nx$ , where  $n$  is the factor expressing the number of times the heated length is longer or shorter than the unheated section. The quantities  $E_{(n+1)x}$ ,  $E_{nx}$ , and  $E_x$  are ordinates read from Figure 2 for the total enclosure length being considered, the heated length, and the unheated length, respectively. The subscripts,  $(n+1)x$ ,  $nx$ , and  $x$  are the length-to-radius ratios for the total enclosure length, the heated length, and the unheated extension, respectively. The complementary relationship also holds,

$$\Delta E_{nx}^x = \frac{E_{(n+1)x} - E_{nx} - E_x}{2} \quad (7)$$

where  $x$  is the length-to-radius ratio for the heated length rather than the unheated length.

The utility of the extension formulas may be demonstrated by specific examples. Take, for instance, a cylinder with an  $L/R$  ratio of 3.0 containing a particle cloud with a  $kR$  value of 1.0. When an unheated extension equal to one-half the heated length is involved, equation (6) is applicable and  $n$  is 2. The heat absorbed by particles while they are in the extension is

$$\Delta E_x^{2x} = \frac{E_{3x} - E_{2x} - E_x}{2} \quad (8)$$

where  $E_x$  is the generalized ordinate for  $L/R$  of 1.5,  $E_{2x}$  for an  $L/R$  of 3.0, and  $E_{3x}$  for an  $L/R$  of 4.5, each being established on the curve,  $kR = 1$ . The points for the  $L/R$  ratios reflect the changes in cylinder length being considered, since the radius is the same for all cases. If there are extensions on both ends of the heated length, calculations are made for each separately. When both extensions are the same, the result for one length is doubled.

In the preceding example, if the unheated length were five times that of the heated section the result would be

$$\frac{\Delta E_x^x}{5x} = \frac{E_{6x} - E_{5x} - E_x}{2} \quad (9)$$

where again  $x$  is the  $L/R$  ratio of the basic heated length. The unheated-to-heated length ratio does not have to be integral. For instance, it may be 5.5 and the additional heat absorption would be

$$\Delta E_{5.5x}^x = \frac{E_{6.5x} - E_{5.5x} - E_x}{2} \quad (10)$$

For each example,  $\Delta E_{nx}^x$ , or  $\Delta E_x^{nx}$ , whichever is needed, is to be added to  $E_b$  for the heated length to obtain the total result for the system.

In performing the calculations for specific cases it may be found that the total absorption ( $E + \Delta E$ ) does not increase very smoothly with increasing unheated length. This condition results from inaccuracies in reading the generalized graph. To obtain improved results, it may be necessary, in particular for  $L/R$  over unity, to construct a larger, more accurate graph by the use of Figures 3 through 7 as already described.

#### D. Application to Other Types of Radiation

While this investigation was concerned with thermal radiation, the basic equations and results are applicable to all forms of electromagnetic and field-emission radiation. One conceivable use might be the evaluation of the radiation dosage an aerosol receives while passing through a cylindrical enclosure with nuclear radiation coming into its interior. The calculation may be made directly if a radiation cross-section value for the suspended particle is known.

#### E. Other Important Variables

For many systems, the described calculations are adequate. Frequently, however, either the wall enclosure or the particle surfaces, or both, are not perfect absorbers and adjustments in the calculations may be required. The emissivity of the wall is first taken into account when the radiation intensity is evaluated; the calculations as described, however, are unaffected at this point. If radiation crosses the enclosure and is intercepted by the wall surface, it is partly absorbed and partly reflected. The reflected energy is available for further absorption by the particles and the infinitely continuing process adds to the heat transfer as more reflections occur. Only the first few, perhaps two or three, need be considered in many cases.

If the energy intercepted by the wall from each emission is evaluated, these reflections may be traced and their contribution to the overall result calculated. It is feasible to attempt these calculations, but a detailed study is required before general conclusions can be stated. It is reasonable to expect, however, that situations with large wall emissivities should correspond very closely to the ideal solution. If, for example, the wall emissivity is 0.75 then only one-fourth of the radiation intercepted by the walls

is reflected. If the aerosol is highly absorbing very little energy reaches the wall, hence the reflected energy may be neglected. If the aerosol is weakly absorbing, a large portion of the energy may be intercepted by the wall, the extent of interception being dependent on the wall-to-wall view factor. When the reflected energy traverses the aerosol, part of it is absorbed therein, and, in terms of a percentage, this part is approximately the same as for the original direct emission. Since a maximum of 25 per cent of the direct emission can be reflected, the additional absorption is no more than about 25 per cent of the first-pass absorption. The maximum absorption occurs only when the wall-to-wall view factor approaches unity. Subsequent reflections may be considered but they contribute little; the second reflection amounts only to about 6 per cent of the absorption by direct radiation. Hence, it may be concluded that, qualitatively, a maximum error due to imperfect wall emissivities can be estimated if the first few reflection processes and the wall-to-wall view factors are considered.

Imperfect absorption by the particles is more complicated. A first approximation for absorptivities less than unity is to multiply the ideal result by the absorptivity of the particles. The results for particle absorptivities less than, but near, unity should be accurate within a few per cent; they may be estimated as above. Further and more precise adjustments are complicated by scattering patterns, changes in attenuation coefficient, and view factor considerations, to mention some of the more important variables. Additional study is recommended. The problem should be considered along with back-radiation to which it is closely related.

Still another area requiring further investigation is the effect of aerosol temperature variations on back-radiation and attenuation coefficients.

It is believed that this work can readily be extended to describe these more involved problems.

#### F. Comparison of Theoretical Development with Experimental Results

Throughout a considerable portion of this investigation, experimental data were collected for aerosols of ferrous sulfide, cupric oxide, and zinc. Particle sizes were chiefly between 20 to 30, 30 to 44, 44 to 53, 53 to 88 microns for the ferrous sulfide and cupric oxide powders and 1 to 10 microns for the zinc. Particle clouds of these materials, when exposed to a radiant heat flux of  $17,600 \text{ Btu/hr ft}^2$  in a 0.0526-foot diameter quartz conduit 1.014 feet long, absorbed up to fifteen per cent of the radiation transmitted through the enclosure wall. The experimental data were employed in testing the theoretical calculations. The comparisons are given in Figures 8 and 9.

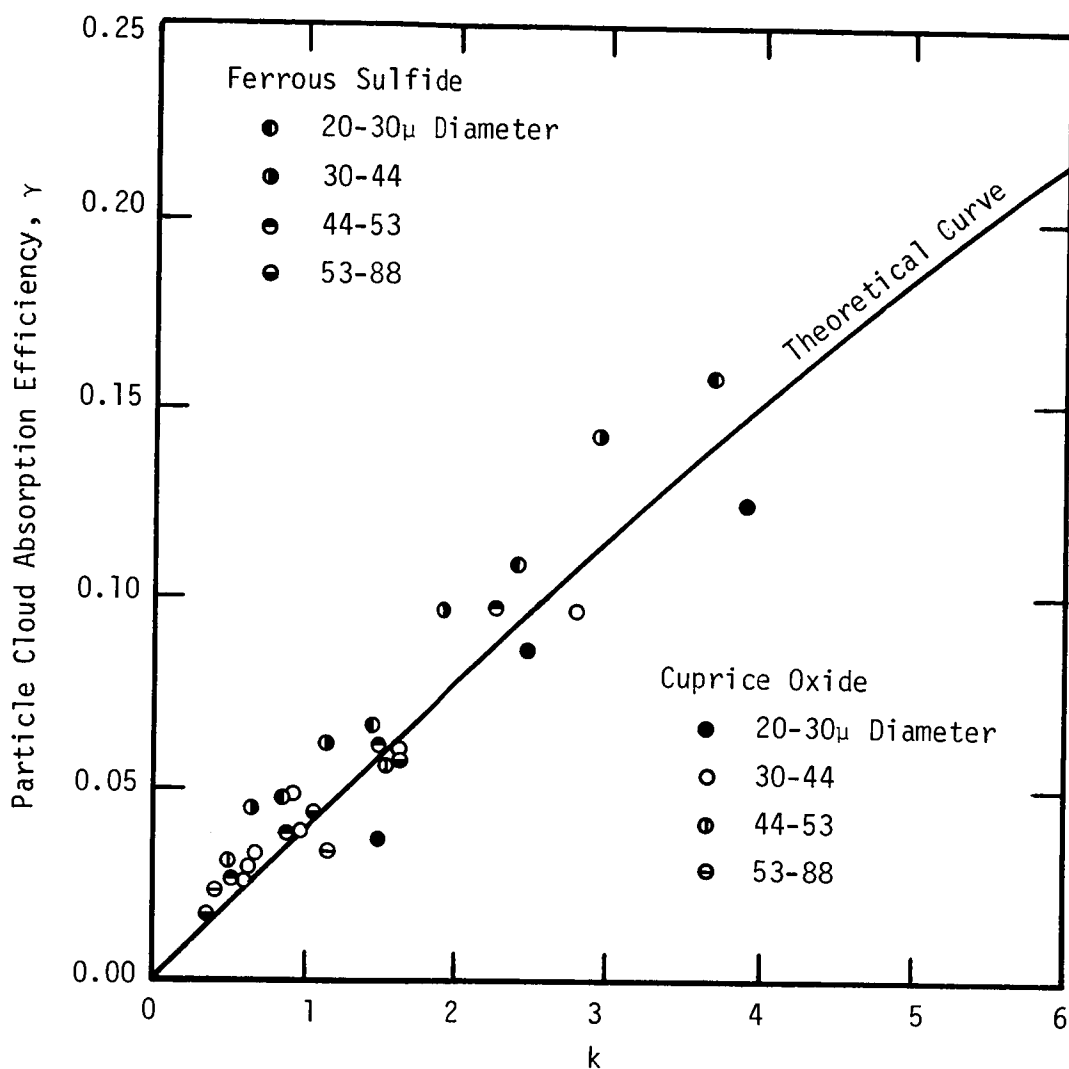


Figure 8. Theoretical Curve and Experimental Data for Ferrous Sulfide and Cupric Oxide Aerosol Relating Absorption Efficiency and Attenuation Coefficient.

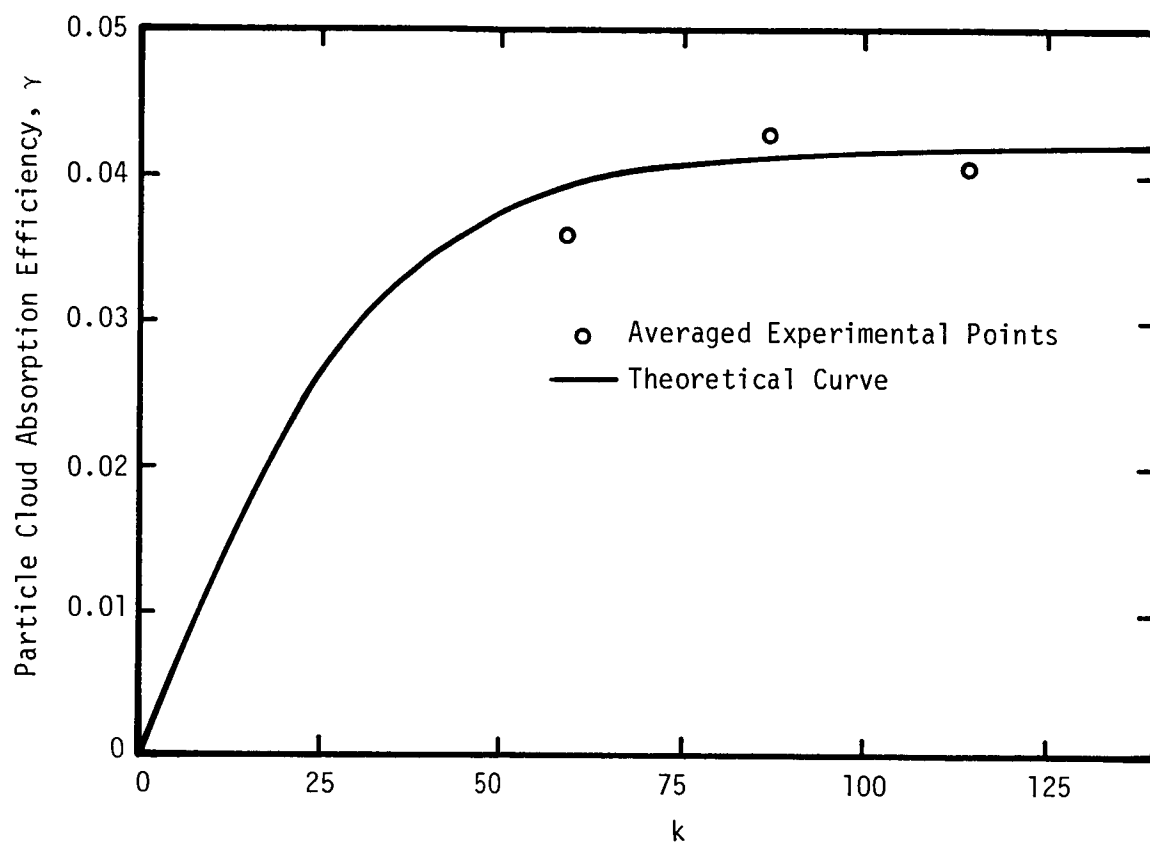


Figure 9. Theoretical Curve and Experimental Data for Zinc Aerosols Relating Absorption Efficiency and Attenuation Coefficient.

#### IV. EXPERIMENTAL STUDIES

##### A. Dispersion of Particles in Gases

Effective dispersion of particles in gaseous media is a problem of fundamental importance to theoretical studies of radiation heat transfer and particle cloud transmissivity. It is also important to practical applications of particle-gas systems for absorbing radiant energy, because a well-dispersed particle cloud absorbs and scatters energy much more efficiently than particle systems having extensive agglomerates.

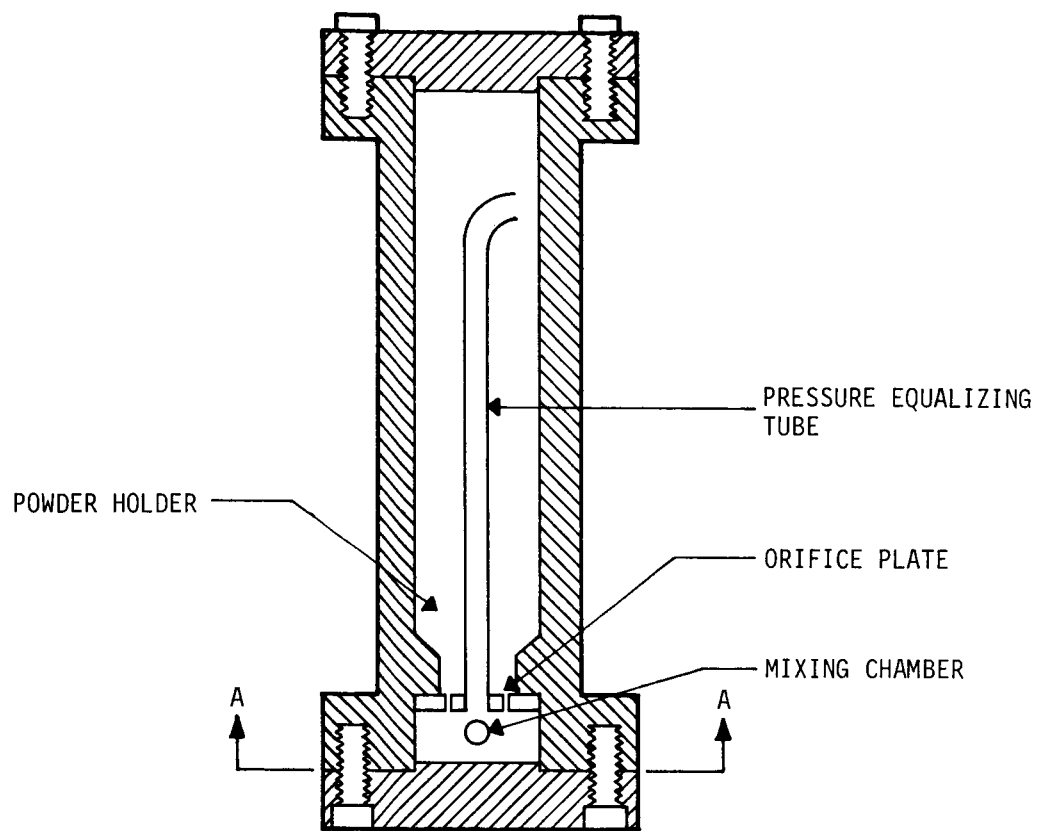
Agglomerates in particle clouds arise from the incomplete separation of powdered materials into discrete particles and from particle agglomeration after dispersion. The degree of dispersion depends on the nature of the powdered material and the effectiveness of the particle-cloud generating mechanism. Particles have mutual attraction mainly because of van der Waals forces, electrostatic forces, and interfacial adhesions caused by surface conditions. One method to improve dispersion efficiencies then is to treat powdered materials for the removal of adverse surface contaminants and for the minimization of electrostatic effects. Another, of course, is to devise methods that produce severe shearing action across small agglomerates, thus effecting better fractionation of them. The latter approach is being pursued.

While there are many different types of particle cloud generators utilizing different mechanisms to disperse particles for various purposes, much improvement in the resulting suspensions is still desirable, particularly for the processing of submicron carbon particles. In this study it is essential that agglomeration be reduced to a minimum and that particle clouds be of invariant concentration. Experiments, testing some possible designs, have been initiated, and devices in which a gas-particle mixture is caused to

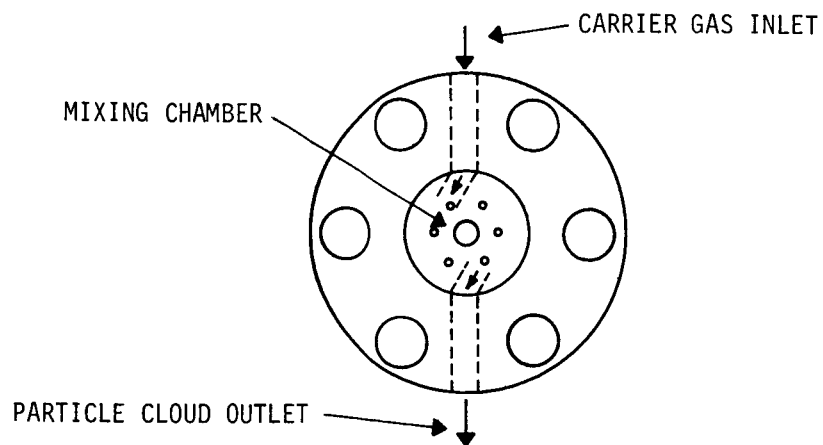
expand suddenly through a small, sharp-edged orifice are being studied. Rapid expansion at the orifice creates an intense shearing action which is capable of acting across very small agglomerates and breaking them apart. Dry nitrogen regulated to pressures of 750, 1000, and 1500 psig is the carrier gas.

The generator being evaluated is shown schematically in Figures 10 and 11. As may be seen from the figures, a powder supply, contained in a high pressure cylindrical enclosure, rests on an orifice plate which has six sharp orifices of  $1/32$  inch in diameter. The powder is caused to feed through the small openings into a mixing chamber by the vibratory action of a Syntron, model F-010, vibrator (Syntron Company, Homer City, Pennsylvania) on which the generator is mounted. Carrier gas, in this case high pressure nitrogen, swirls through the mixing chamber and entrains the particle clusters. From there the newly formed suspension flows through a short, small tube and emerges from a sharp-edged, circular orifice, 0.016 inch in diameter. The rapid expansion and associated high shearing action effectively transforms the agglomerated suspension into a much improved dispersion of particles. The process is made still more effective by the impingement of the gas-particle mixture on an impactor plate located approximately  $1/4$  inch from the orifice.

Particle clouds of submicron carbon particles (Spheron 6, Cabot Corporation, Boston 10, Massachusetts) have been produced by this technique and their degree of dispersion have been deduced from electron micrographs collected with a Goetz, model E, spectrometer (Zimney Corporation, Monrovia California) and a Numinco, model MIC-501, thermal precipitator (Numinco, Monroeville, Pennsylvania). While these sampling instruments appear to be



LONGITUDINAL SECTION OF POWDER FEEDER



SECTION A-A

Figure 10. Particle Cloud Generator.

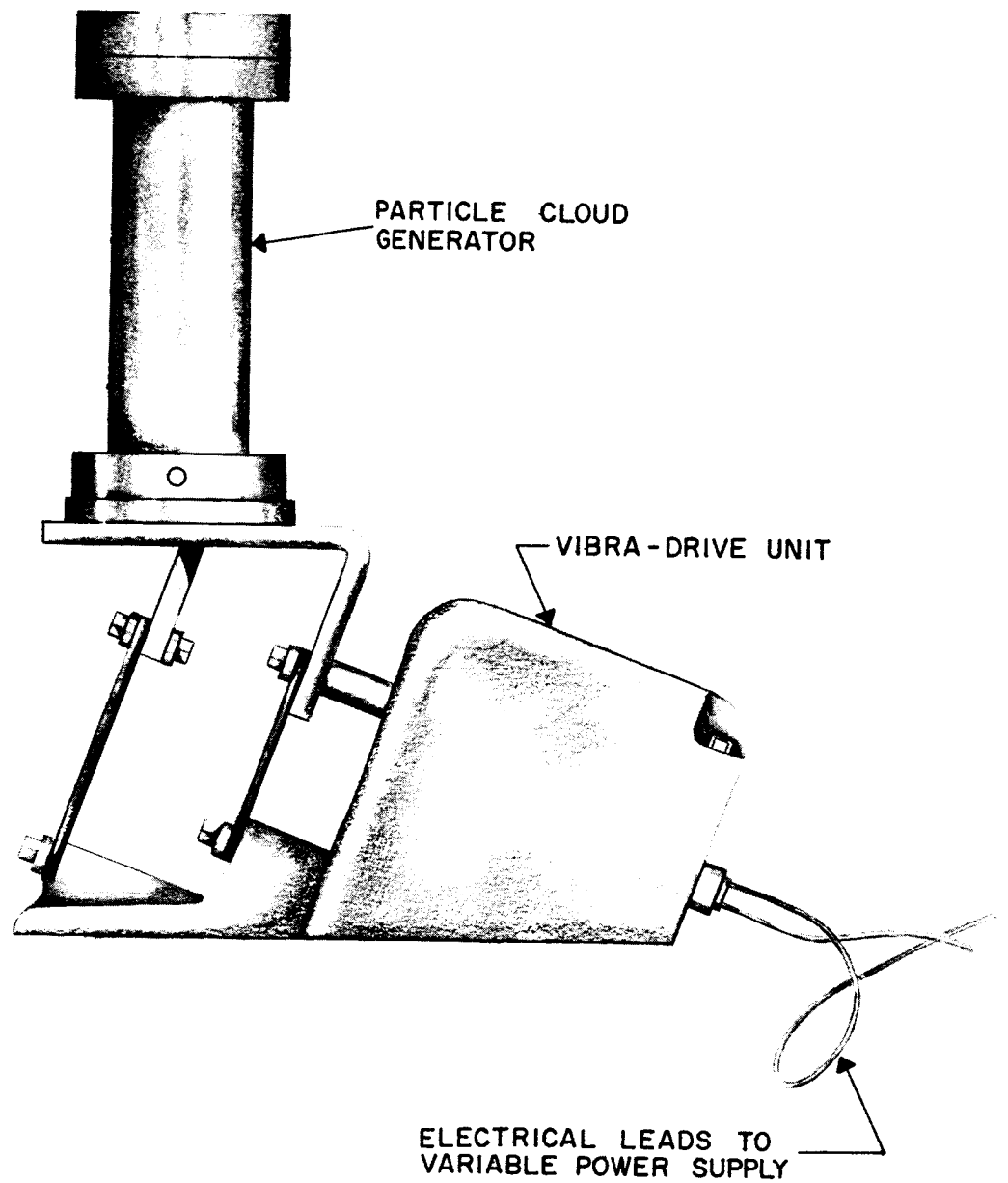
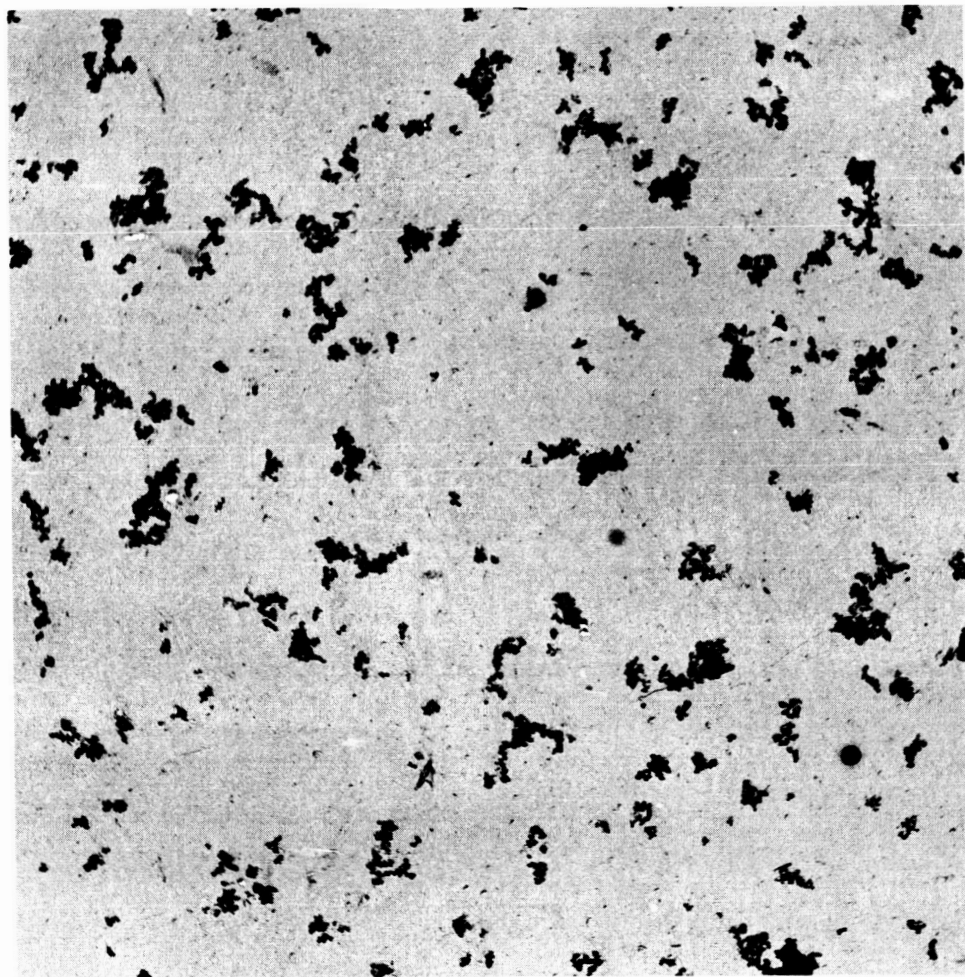


Figure 11. Syntron Vibra-Drive Unit and Particle Cloud Generator Assembly.

adequate for the present studies, it must be remembered that the indicated degree of dispersion is highly dependent on the collection procedure and the methods of microscopic examination. Caution must be exercised in deducing particle and agglomerate sizes from such suspension deposits. For this electron micrographs are required.

The Goetz aerosol spectrometer is a device which offers quantitative collection and size classification of air-borne particles. Its principle of operation is based on the application of intensive centrifugal forces to a continuous, laminar-flowing stream of the aerosol. The device is constructed with two identical helical channels on a conical rotor such that, when the rotor is turning at a high rate of speed, particles passing through the channels are deposited according to size along the outer surface of the helical channel. The covering surface is formed by paper, plastic, or thin metal sheet wrapped around the rotor and may be removed for studying the collected particles. While the instrument has been found capable of fractionating particle sizes along the channel length, the submicron carbon particles employed here were not separated according to size. At rotor speeds of 12,000 rpm, however, a suitably dilute deposit for microscopic study was obtained. The collection efficiency was about fifty per cent as determined by passing the exhaust gas through a millipore filter (Type GS, Millipore Filter Corporation, Bedford, Massachusetts). The low collection efficiency indicated that the dispersion was very good and many particles including agglomerates were less than 0.2 microns. Micrographs of the particles collected by the Goetz aerosol spectrometer are given in Figure 12, where the larger size agglomerates are represented.



1 $\mu$

Figure 12. Carbon Black Particles Collected by Goetz Aerosol Spectrometer.

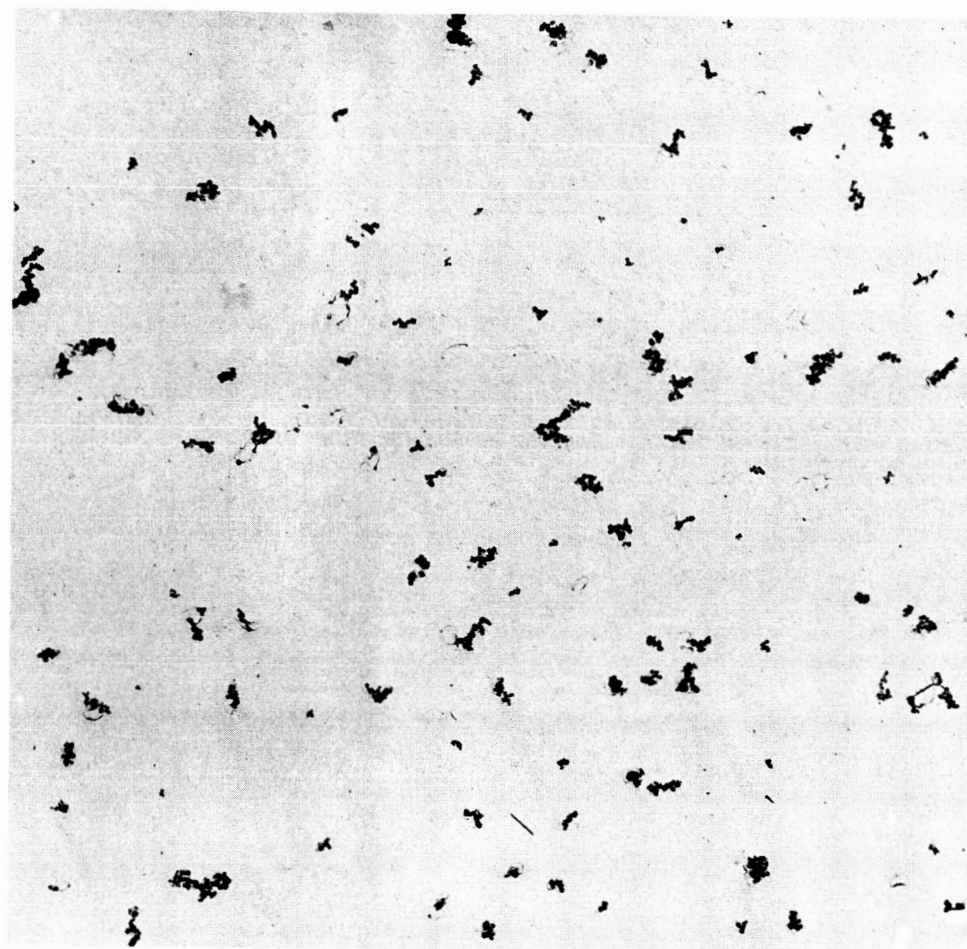
Particles not collected by the Goetz aerosol spectrometer were collected by thermal precipitation\* and the deposits were photographed for observing the size of the escaping particles. The results are given in Figure 13. As shown, the agglomerates still contain several particles but the total size of the agglomerates is quite small (less than 0.2 micron). These results are encouraging since, these particles were shown to constitute over half of the dispersed mass.

#### B. Radiation Transmissivities of Particle Clouds

The radiation transmissivities of carbon particle clouds are being studied with the particle cloud generator described. As yet, only exploratory observations have been made, but it appears that a satisfactory basic system for the investigation has been assembled. Modifications, however, are expected. A Beckman, model B, spectrophotometer (Beckman Instruments, Inc., South Pasadena, California) is serving as the transmissivity measuring device. The assembly of the main component parts of the apparatus is shown schematically in Figure 14. There it may be seen that an aerosol is generated and directed into a surge chamber from which it emerges at an essentially constant particle concentration into the rectangular duct leading to the spectrophotometer. A long channel is provided to create a steady flow condition in the region where the transmissivity measurements are made. A thin jet of air adjacent to the windows keeps them from being clouded by deposited particles.

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\* Thermal precipitation is the collection of particulate matter from an aerosol by the passage of the aerosol between two, closely spaced plates (usually less than 0.015" apart), one heated and one cooled. The thermal gradient between the plates drives the suspended material to the cooler surface. The collection efficiency is for practical purposes one hundred per cent complete.



$1\mu$

Figure 13. Carbon Black Particles Leaving the Goetz Aerosol Spectrometer and Collected by Thermal Precipitator.

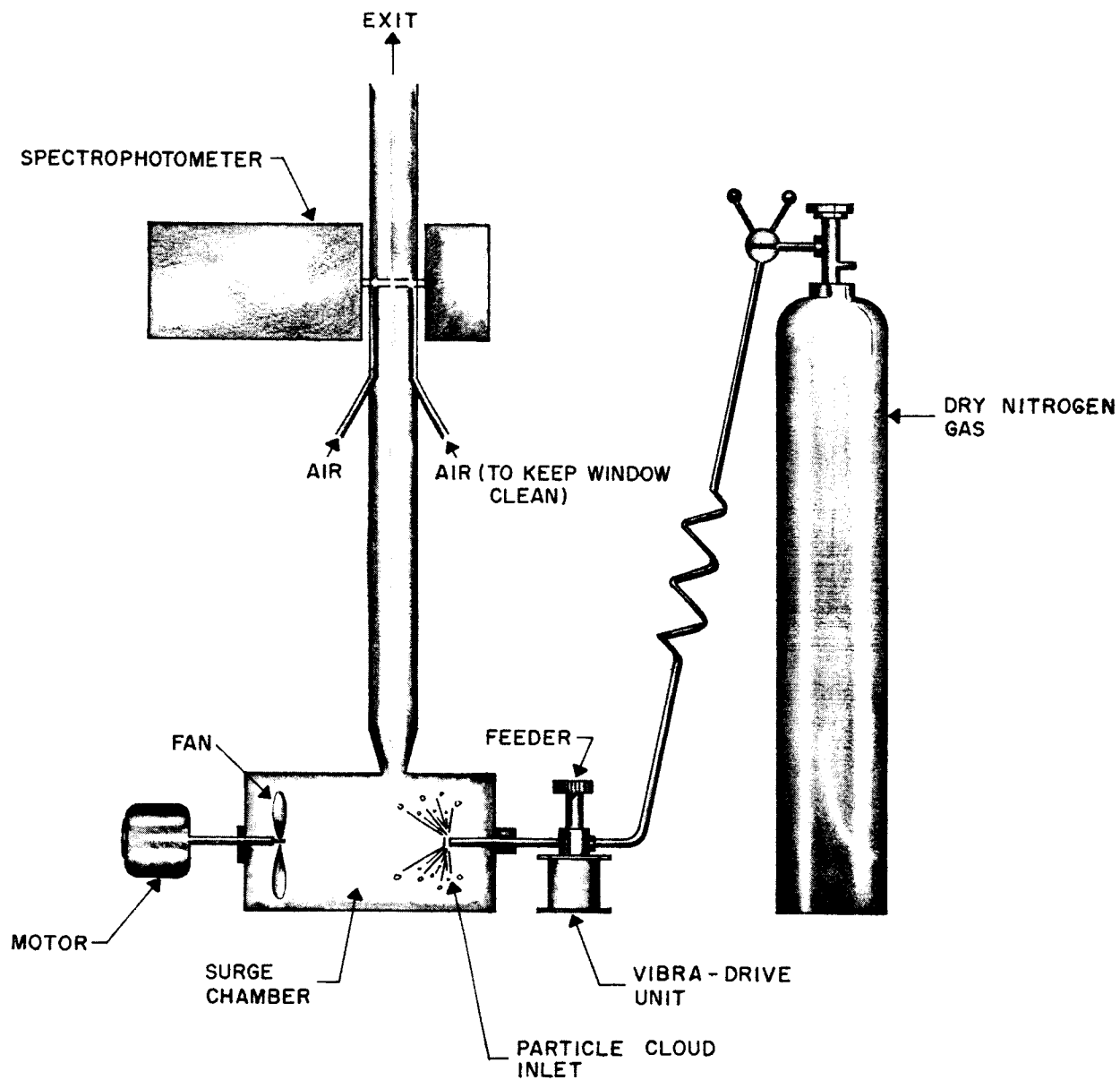


Figure 14. Apparatus for Measuring Particle Cloud Transmissivities.

Data are being taken of the transmittance and absorbance of known aerosol particle concentrations at specific wave lengths of the light passing through the aerosol. The attenuation is to be evaluated by the relation

$$I_s = I_o e^{-kS} \quad (11)$$

where  $I_o$  and  $I_s$  are the initial and final intensities after passing a distance  $S$  through the aerosol. The quantity  $k$  is the attenuation coefficient and may be shown to be

$$k = -\frac{1}{S} \ln \frac{I_s}{I_o} \quad (12)$$

The ratio  $I_s/I_o$  is defined as the transmittance.

## V. FUTURE WORK

It is anticipated that work in the near future will be primarily experimental; each area of interest -- heat transfer, particle cloud generation, and radiation transmissivity -- is to be pursued. The means of investigation for the latter two values have been defined herein. Plans for additional heat transfer measurements are being made but the experimental system has not been completely designed. An apparatus radically different from the one previously employed in this study is to be constructed, however. Tentatively, a tungsten tube is to be heated electrically and the heat transfer to clouds of sub-micron particles passing through it is to be determined. It is desired to construct the new system with a length-to-diameter ratio of about one and to have the diameter as large as possible. It appears that electrical power limitations will set the maximum diameter between one and two inches. It is planned that a tube wall temperature of 4000° to 5000°F will be achieved.

Respectfully submitted,

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Approved:

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